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ETL-0552

AD-A216 516

Expert System for Minefield Site Prediction

Phase III

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November 1989

Prepared for:

U.S. Army Corps of Engineers
Engineer Topographic Laboratories
Fort Belvoir, Virginia 22060-5546

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
November 1989

3. REPORT TYPE AND DATES COVERED
Technical Report: Dec 88 - Nov 89

4. TITLE AND SUBTITLE
Expert System for Minefield Site Prediction--Phase III

5. FUNDING NUMBERS
DACA72-86-C-0017

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
PAR Government Systems Corporation
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Topographic Laboratories
Fort Belvoir, Virginia 22060-5546

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
ETL-0552

11. SUPPLEMENTARY NOTES
Expert System for Minefield Site Prediction--Phase I, ETL-0492, Feb 88, AD-A192 990.
Expert System for Minefield Site Prediction--Phase II, ETL-0534, May 89, AD-A207 361.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report reviews the major system components of the Minefield Site Prediction Expert System (MSPES) and discusses enhancements made to the systems under Phase III of this contract. Phase III extended the knowledge base and significantly enhanced the operation of the system, both in the processing methods and analyst interaction with the system. Additional detailed descriptions of the MSPES and its architecture may be found in Phase I and Phase II Reports (ETL-0492 and ETL-0534). Phase III MSPES development continued on the Sun 3/160, using the Sun operating system and the X Window System graphics software package. A knowledge base was implemented which incorporates enemy location factors.

14. SUBJECT TERMS
Expert System, Minefield Site Prediction, GIS (Geographic Information System), Quadtree, Window System, Terrain Analysis, Minefield Doctrine

15. NUMBER OF PAGES
40

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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Table of Contents

List of Figures

Preface

This report describes the work performed under Phase III of Contract DACA72-86-C-0017 for the U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia, by PAR Government Systems Corporation, Reston, Virginia. The period of performance covered by this report is December 1988 through November 1989. This is the concluding phase of a three year contract. The contracting officer's representative was Mr. John Benton, of the Research Institute, CEETL-RI-I.

1. Introduction

This report describes work performed during the period from February 1989 through November 1989 under Phase III of contract DACA72-86-C-0017, Expert System for Minefield Site Prediction.

1.1 Scope of the Report

This report reviews the major system components of the Mine Site Prediction Expert System (MSPES) and discusses modifications made to the system under Phase III of this contract. Phase III development was a natural extension of the system developed under Phase II. A high-level description of the software architecture was presented in an earlier document from Phase I [Barth *et al*, 1987], with more detailed descriptions presented in the Phase I and Phase II Final Reports [ETL-0492, February 1988; ETL-0534, May 1989].

The organization of this report is as follows. Section 2 provides an overview of the system. A description of the various components is presented in Section 3. Section 4 contains some recommendations based on evaluation of the Phase III developments.

1.2 Scope of the Phase

The scope of Phase III was the implementation of a second knowledge base which incorporated enemy location and line of sight factors for minefield site prediction. Phase III MSPES development continued on the Sun 3/160 at the request of the ETL. The transporting of the system to the target computer, a VAXStation II GPX, was scheduled for Phase III. Based on the review and evaluation at the end of Phase II, however, it was determined that the system should not be transported to the VMS environment. Phase III effort was concentrated in two areas: first, the implementation of a second processing methodology and, secondly, the implementation of a second knowledge base.

1.3 Summary of Work Performed

The major results of the work performed under Phase III were the following:

• *User interface implementation* . To make the MSPES more transportable to other machines, the user interface under Phase II was implemented using the X Window System (X11), a graphics package originally developed at the Massachusetts Institute of Technology (MIT). Phase III extended the X Window implementation to enhance analyst interaction with the MSPES. Several modifications were made in the window system interface software to adapt to the changes that occurred between release 2 and release 3 of the X11 Window System.

• *Rule base development.* The knowledge base expansion in Phase III was significant. Based on analyst input, reasoning involving enemy location and visibility was incorporated in the rule base.

• *Processing efficiency.* An additional processing method was developed which takes advantage of the GIS functions and uses Boolean operations to form an inference template. This process, combined with some modifications to the manuscript update software, decreases the inference processing and thus dramatically reduces processing time for production of a minefield manuscript.

2. Overview of the System

The goal of the MSPES is to automate some of the functions performed by the terrain analyst and the combat engineer in the determination of potential minefield sites. The factors used in minefield site prediction include terrain information, such as mobility information; mine and countermine warfare doctrine, as found in military training manuals; and battlefield situation or enemy intention knowledge, as supplied by battlefield intelligence. Developing the MSPES involves elements of military terrain analysis, which in turn encompasses both geographic analysis and military doctrine. The system therefore comprises a geographic information system (QUILT) for handling the terrain information; an inferencing mechanism (ERS) for coordinating rules about how the doctrine exploits the terrain information in making minefield site predictions; and a direct manipulation user interface based on a windowing graphics package (X11) to provide the analyst working in this domain with a consistent, intuitive environment for interacting with the GIS and the inferencing mechanism.

The individual system components (QUILT, ERS, and user interface) were previously discussed in the Phase I and Phase II Final Reports. Phase III modifications and enhancements to the system components are discussed in detail in Section 3. In this section, a scenario is presented that describes how manuscripts are created. The scenario illustrates the interactions among the system components, and details the two processing methods developed.

2.1 An Illustrative Scenario

The terrain overlays associated with an Area of Interest (AOI) and a rule base are the necessary inputs to start the process in which the ERS inference engine may run. The textual rule base that the analyst has selected is read from a disk file and is compiled. The compiled rules become the inference network for ERS. The inference network drives the process of gathering evidence for the various hypotheses about a location being a mine site.

Locations to be evaluated are specified to ERS by the **Create Manuscript** application or the **Explain Manuscript** mode of the **View Map** application. The **Create Manuscript** application gets its AOI locations from a geographic primitive, whereas the **Explain Manuscript** mode of the **View Map** application gets its AOI locations from the analyst interactively.

The evidence in support of ERS's inferential hypothesis comes from GIS primitives. The primitive processes that ERS uses are started as needed following the compilation of the inference network. The relationship of the terrain characteristics relative to a location provide evidence to ERS. ERS uses this evidence as the basis for an evaluation of the likelihood of the location being a mine site. The evidence in support of the possible hypotheses is evaluated and the hypothesis with the highest 'score' becomes the evaluation for the specified location.

The **Create Manuscript** application sends this evaluation back to the geographic primitive that initially reported the location coordinates. This primitive updates the value associated with the location to reflect the mine site likelihood evaluation. Since the data base file used for this purpose is never accessed by ERS, this evaluation does not bias later evaluations. The **Explain Manuscript** mode of the **View Map** application reports the evaluation and related rule base information to the analyst through a window-based interface to ERS. The analyst may review the evaluation in terms of the evidence compiled supporting the hypothesis and the inferencing process and may choose to edit the manuscript, edit the rule base, or to accept the evaluation.

2.2 Method I

To produce a minefield manuscript using Method I, the analyst first specifies enemy location(s) if known. Upon completion of the enemy location edit process, overlays that are dependent on enemy location are created. These include the calculation of forward facing slopes (areas that are visible from enemy locations) and ranges of minimum distance to enemy location. If enemy location is not known, these processing steps are simply omitted and the minefield likelihood evaluation will be based solely on terrain factors and other "permanent" data if available. The analyst then selects an overlay to serve as the template for a minefield manuscript production. This overlay will be the guide for the inferencing process, indicating which areas should be evaluated. Any areal overlay may be used, for example, the off-road mobility overlay is often used as the template for a manuscript.

For each area in the selected manuscript template:

- The GIS passes an area identifier to the Create Manuscript application to be evaluated by the inferencing mechanism.

- The application passes the area identifier to ERS, the inferencing mechanism.

- ERS, driven by the inference net, calls GIS primitives required to make a final evaluation.
- ERS passes its evaluations, as they are made, back to the application.
- The application passes the final evaluation back to the GIS.
- The GIS updates the current quad with the final evaluation value.
- The next area identifier is found.

2.3 Method II

To produce a minefield manuscript using Method II, the analyst also specifies enemy location(s) if known. This part of the process is the same as under Method I.

With Method II, the manuscript template is constructed by combining (intersection overlay operation) all of the overlays to create quads with a unique value wherever a different combination of attribute values exist. This is done by first combining the overlays that contain multiple attribute values, such as the mobility and distance range to enemy location overlays. Subsequently the overlays that merely denote the presence or absence of an attribute value, e.g., areas that are visible or not from enemy locations, are combined with the results of the previous step. The result is a manuscript template which defines an identifying value for each unique combination of attribute values for every location of the area of interest. Finally, each unique combination of attributes is marked as 'unevaluated'.

For each unevaluated combination of attributes in the manuscript template:

- The GIS passes an area identifier to the Create Manuscript application to be evaluated by the inferencing mechanism.
- The application passes the area identifier to ERS, the inferencing mechanism.
- ERS, driven by the inference net, calls GIS primitives required to make a final evaluation.
- ERS passes its evaluations, as they are made, back to the application.
- The application passes the final evaluation back to the GIS.
- The GIS updates this area and every other area whose value indicates it has the same combination of attributes with the final evaluation value.
- The next unevaluated combination of attributes is found.

This processing method was shown to be at least five times more efficient than Method I. The processing time to complete Method I is dependent on the number of areas with a homogeneous value in one of the areal overlays; using the **nodect** QUILT function, this number was calculated to be over 29,000 for the Lauterbach mobility overlay. Processing time to complete Method II is dependent on the number of unique combinations of attribute values for all the overlays in an area of interest; for the 10 or so overlays currently available for use by the MSPES this number typically was shown to be less than 200. The typical processing time to produce a minefield manuscript for a 1:50000, 25 km X 25 km area, is about ten minutes run time on a Sun 3/160 using Method II. Using Method I, processing time can exceed one hour. Figure 2-1 demonstrates the difference between Method I and Method II.

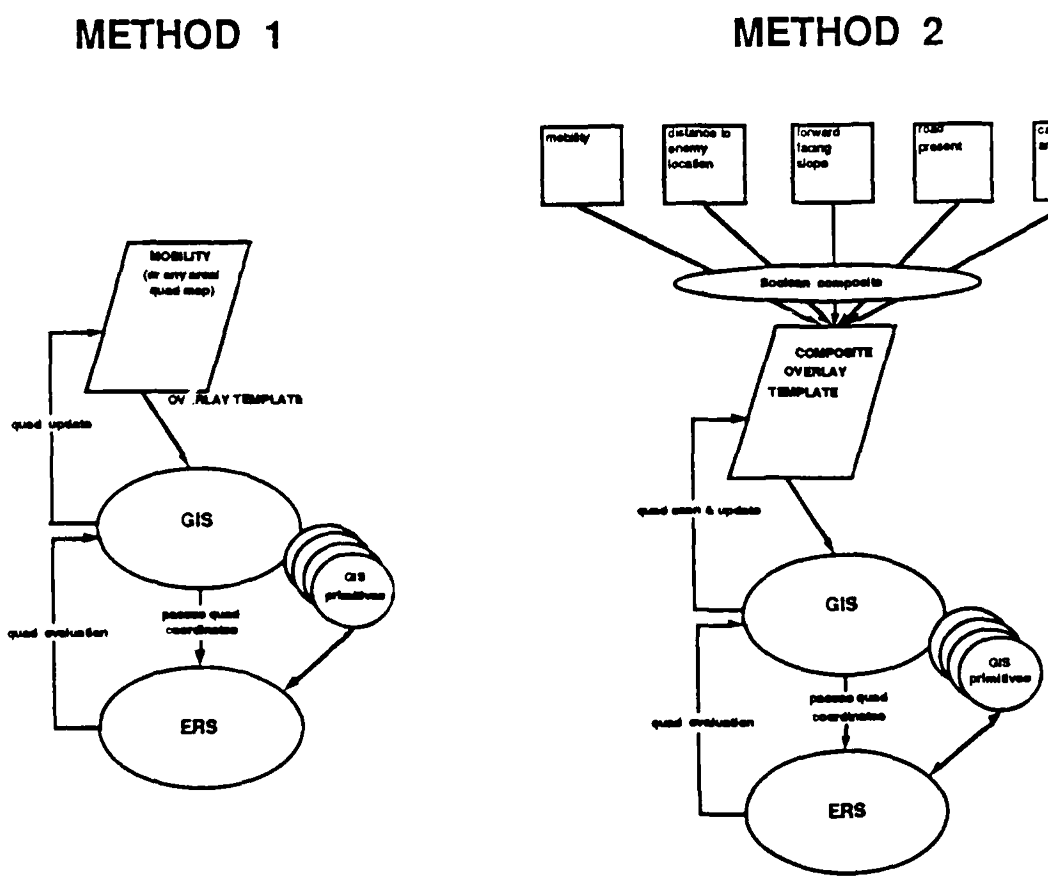


Figure 2-1. Processing Methods I and II.

3. System Software Description

The Phase II MSPES software components are organized as shown in Figure 3-1. MSPES Applications, the Inference System, and the Geographic Information System access rule bases, terrain data, and map descriptions which are defined in disk files. MSPES Applications and the Inference System have user interface components which use Window System Interface routines to present textual and graphic displays to the user. MSPES Applications, the Inference System, and the Geographic Information System communicate data amongst themselves as each requests it. The MSPES Applications and the Inference System communicate with the GIS via GIS primitive processes, each of which answers simple queries of the data base maintained for an Area of Interest. This overall organization is fundamentally the same as that used for the first two phases of MSPES development. The succeeding sections will discuss the major modifications to the MSPES during Phase III, using reference to earlier Phases for background information.

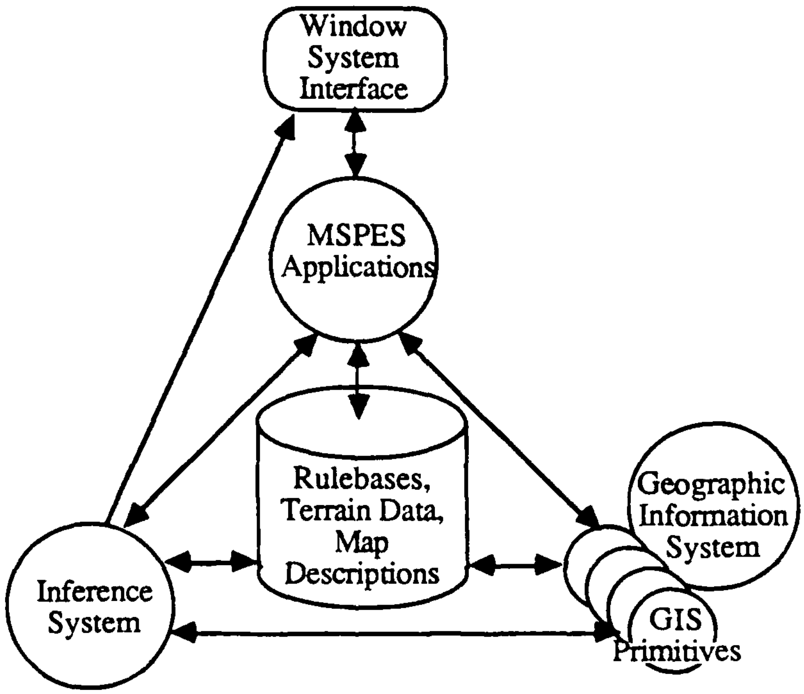


Figure 3-1. MSPES Phase III Components.

3.1 Input Conversion

The Phase II MSPES uses two basic types of information to support its rule base evaluation of terrain characteristics: vehicle mobility data derived from the Condensed

Army Mobility Model System (CAMMS) and transportation network information derived from ADDWAMS transportation features. In Phase III, both off-road mobility and on-road mobility were provided in CAMMS format in addition to elevation data. The CAMMS data used for Phase III development and testing, provided by the Waterways Experiment Station (WES), was in a different format than that used for Phase II CAMMS data. The different formats and the addition of elevation data in Phase III necessitated modifications to a number of existing procedures and the development of some new software to integrate this format data into the MSPES GIS component. Procedures and programs to convert the older, Phase II CAMMS and ADDWAMS data formats, as well as the Phase I SLF data formats, are still separately available. Not all of the procedures necessary to prepare data for evaluation with the Phase III rule base are able to use the older data formats, however. For example, the programs and procedures that convert the CAMMS road data used in Phase III to areal quadtree form were not set up to deal with the ADDWAMS format road data used in Phase II.

3.1.1 CAMMS processing: Off-Road Mobility

CAMMS areal attribute data, including off-road mobility information, is imported to the system as a raster of polygon identifiers keyed to attribute look up tables for areal attributes unique to each polygon. The mobility information is provided as an attribute look up table of speed values for a particular vehicle type across the terrain of a map sheet given specified weather conditions. The MSPES **camms_cvl** process converts import format polygon identifiers into a raster format used by the GIS. The MSPES **cnvrt_attr** process converts the import format attribute look up table to a format more amenable to handling by other MSPES processes. The **speed2ccm** process combines the polygon identifier raster and the CAMMS mobility speed value attribute into mobility categories (go, restricted, slow, etc.) as the raster is converted into the input format used by the QUILT package. The default mobility category breaks are easily over-ridden at run time to assign different speed values to the mobility categories. The mobility categorized CAMMS data is converted to an areal quadtree using the QUILT **build** procedure. The resultant mobility quadtree is used directly by the Inference System as well as indirectly via the derived overlay of channelized areas. Figure 3-2 illustrates the processes used in converting CAMMS mobility information into a mobility category quadtree.

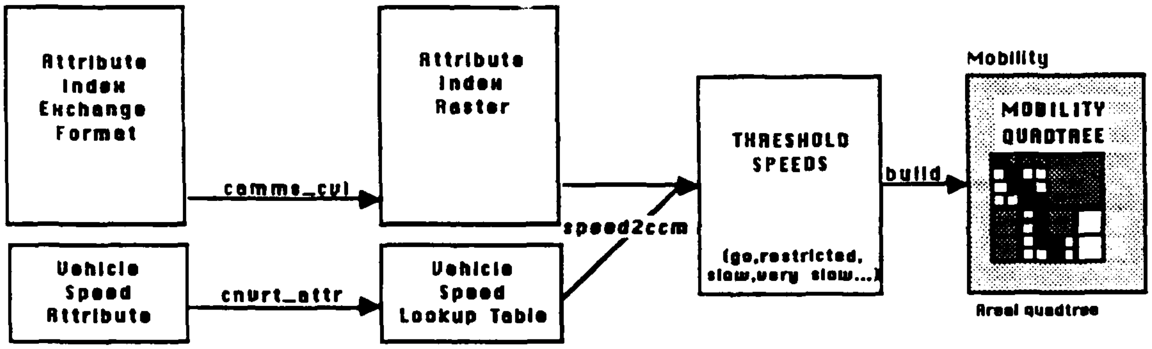


Figure 3-2. Conversion of CAMMS Data to Mobility Quadtree.

3.1.2 CAMMS processing: On-Road Mobility

The Phase III MSPES derives transportation feature information from linear descriptions of transportation features in CAMMS format. The CAMMS linear data format is converted to the format used to import *areal* data into the system. The reason for converting linear information to an areal representation was made necessary by the approach taken during Phase III toward minefield site determination; namely, the evaluation of unique combinations of attributes rather than distinct positions in the area of interest. This necessitated that all the terrain attributes be maintained in a format that enabled them to be combined to form unique combinations of attributes. The QUILT GIS being used by the MSPES, though it does support storage of areal, linear, and point data in quadtree format, does not provide any integration between these data types. As a result, overlays used by the MSPES during Phase II developments that had to be combined using boolean operations to determine unique attribute combinations were all maintained in areal format quadtrees. Since the Phase III rule base incorporates information about areas adjacent to or on road network segments, the approach taken during Phase III toward the CAMMS road network data was to map it onto a raster (at the same resolution as that used by the other overlays). The result yielding data about areas 'near' roads. Of course, there are several obvious problems with this naive approach: no attempt was made to determine areas within a specified distance of road centerlines, only raster elements touched by the road centerline data are considered 'near' roads; and, at 100 meter resolution, a road segment could be as far as 70 meters from the center of the raster element that the road segment touches. However, the approach taken was to demonstrate how road network data could be utilized by an inferencing mechanism, not to provide a rigorously accurate linear network representation.

To convert the linear network information to the appropriate format, the **line_to_cvl** process reads the linear data format and creates the data format used to import areal data into the GIS. Because of the density of the road network in Germany, options for the **line_to_cvl** process permit it to process only specified classes of roads, e.g. those classified as super highways and primary roads. Figure 3-3 illustrates the processes used in converting CAMMS On-Road mobility information into a areal quadtree identifying areas near roads.

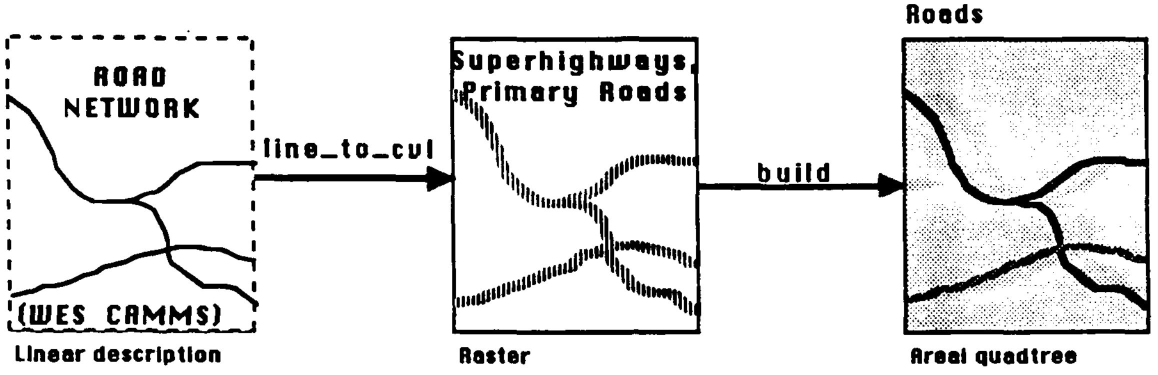


Figure 3-3. Conversion of CAMMS On-Road Data to Quadtree.

3.1.3 CAMMS processing: Elevation Data

Phase II rulebase developments required that enemy locations be provided in order for a more complete rulebase evaluation to occur. One attribute of evidence used by the rule base that is derived from enemy locations is the subset of the area of interest that is visible from the enemy locations. To obtain this evidence, DTED derived elevation data that was provided with the Lauterbach attribute information was used. The **camms_cvl** process is used to convert the elevation data, in CAMMS format, to a binary raster format. The **fslp** process, which was developed by adapting an algorithm from the Radial Terrain Masked Area software provided by the ETL Air Land Battle Environment (ALBE) group, determines the forward facing slopes visible to enemy locations. The **elev_range** process converts the elevation data into elevation range class polygons, a format more amenable to storage in the GIS and for terrain visualization through the user interface. Figure 3-4 illustrates the processes used to convert elevation data and enemy locations provided by the analyst to overlays used by the system for user orientation or rule base evaluation.

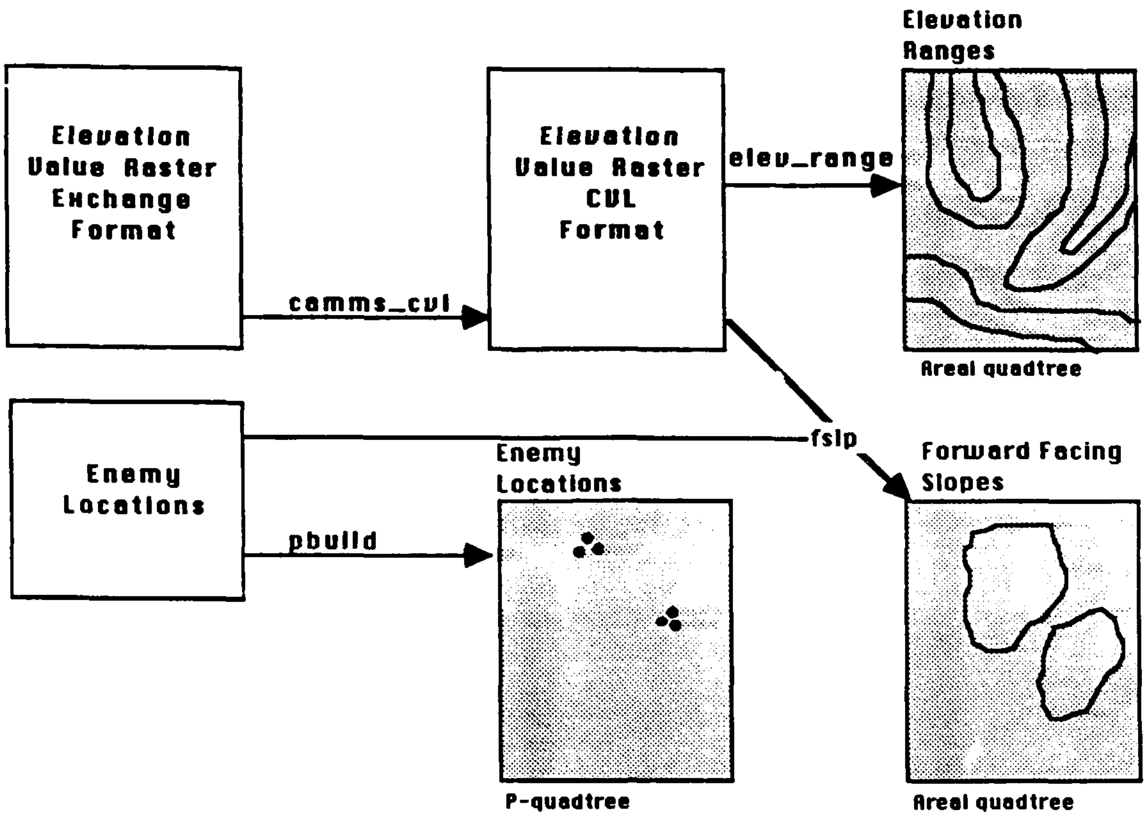


Figure 3-4. Conversion of CAMMS Elevation Data Quadtrees.

3.2 Inference System

The Inference System that is used by the MSPES is ERS, the Embedded Rule-based System. ERS is run as a separate process by the MSPES applications that require access to the Inference System. ERS, in turn will start separate GIS Primitive processes corresponding to the pieces of geographic information that a rule base requires.

3.2.1 Rules

The purpose of the MSPES rule bases is to determine the likelihood of a minefield being present at a certain location. Five categories of likelihood may be assigned: *Very Likely*, *Likely*, *Possible*, *Unevaluated*, and *Not Likely* Each one of these goals is represented by a separate rule base goal node. The Phase III rule base uses only the first four possible goals.

The rule base developed during Phase III is totally separate from rule bases I and II which were developed during the first and second phases of this contract. The Phase I and

Phase II rule bases were designed to support one another, with one rule base focusing on terrain factors and the other focusing on battlefield situation factors. The Phase III rule base is a single, stand-alone rule base. With the development of Method II processing, the gains in efficiency made the single rule base approach a viable option and eliminated some of the user confusion that could result from having to evaluate two rule bases in sequence.

There were several domain assumptions made under this effort. These assumptions are listed below:

1. The enemy has their mines placed in position for a deliberate defense.

2. The enemy can be located anywhere on the map and if the enemy position is known, the forward facing slopes are determined based on a line of sight data calculation.

3. Possible minefield sights may be determined with or without a known enemy position.

4. The rule base is constructed primarily for the data acquired to date, including: mobility, transportation, forward slope, elevation, and canalization. All data are for the Lauterbach (Hessen) quad in West Germany provided by WES or subsequently derived from this data through calculation.

5. Evidence and hypothesis nodes were incorporated into the rule base for which there was no supporting data. The main purpose of this was to consider these possibilities if the data should become available. Examples of this data include key installation data, man-made obstruction data, and avenues of approach.

There are several nodes which rely on data that was not available or currently accessible. These evidence nodes were included in the rule base mainly to demonstrate the many factors that help determine where a minefield site may be located. The majority of the nodes included in the rule base are logical nodes. The logical node format allows the analyst to answer yes or no to every question if running in consultation mode. The answer provided by the user is converted to a degree of belief for the evidence node before inferences are propagated. If the analyst wishes to respond so that no inference is propagated, or if the system is running automatically and the data is not available, then a 0 is entered by the analyst or returned by the primitive manager. A detailed list of the Phase III rule base nodes is provided in Appendix C.

The knowledge represented in the rule base came from several different sources. Information from experts was incorporated into the rule base as well as information from military mines placement doctrine.

Two of the experts interviewed for minefield site prediction were Captain Brian Green of the U.S. Marine Corps and Captain Jonathan Clark of the U.S. Army. These interviews were conducted at the Defense Mapping School in Fort Belvoir, VA. Knowledge was also obtained from in-house military experts with a background in troop movement and mines placement.

Much of the information included in the rule base came from military doctrine included in DoD technical reports provided under this contract. These reports include:

ETL—0325 Using Terrain Analysis to Predict Likely Minefield Sites, Robert A. Falls, U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, Va., May 1983.

FMS—102 Countermobility, Headquarters Department of the Army, Washington, D.C., 14 March 1985.

The Handbook for Employment Concepts for Mine Warfare Systems, HQ U.S. Army Engineer School, Ft. Belvoir, Va., 1 August 1986.

The mobility information was taken from information provided primarily by Cary D. Butler of the Waterways Experiment Station (WES), Department of the Army, Corps of Engineers, Vicksburg, MS. The mobility data covers many categories of cross country movement for both on-road and off-road movement. Off-road categories include: USCS soil type; soil strength (in CI or RCI); surface condition (slipperiness); snow characteristics; trapezoidal obstacles — slope, height, width, length, angle, juxtaposition; surface micro-geometry (roughness); vegetation — density, distribution, visibility. The on-road prediction model includes: road type; soil type; soil strength; surface condition; snow data; slope; visibility; micro-geometry, AASHTO speed (road curvature).

The four goal nodes of the Phase III rule base are all propagated via Bayesian techniques. This means that the higher weight an intermediate node is assigned, the more that node will influence the determination of the goal outcome. This can be done with both positive and negative weights. Using this technique allows greater weight to be given to the intermediate nodes for which there was evidence or data. Of the four nodes that are antecedents of the four goal nodes, the two for which data existed to support the evidence are **terrain_fac** and **e_location**. Logically, these two nodes had the greatest affect on the outcome of the goal and were weighted with greater strength than the other two antecedent nodes of the goal nodes: **adjacency** and **key_area**.

3.3 Geographic Information System

During Phase II developments, modifications were made in the way the Geographic Information System, QUILT, is used. The architecture of GIS usage by the Phase III MSPES remains the same as that used in Phase I and Phase II: some GIS 'primitives' are used to feed information to MSPES application programs and update the data base while other GIS primitives are used by the Inference System to provide information about terrain characteristics in support of rule base evaluation. The modifications made under Phase II were in two areas: the way applications use GIS 'primitives' to feed them information, and the GIS primitives used by the Inference System. The discussion below details these modifications for background information and reference.

3.3.1 Application Use of GIS

Previously the MSPES used slight modifications of the native QUILT capabilities to drive the display of terrain information. Two modifications were made during Phase II to improve application performance using the GIS. The display of areal quadtrees is now significantly faster. Previously areal quadtree display was achieved by traversing the quadtree and issuing a display command for each quadtree leaf node, specifying its upper left corner coordinate and the size of the leaf node. This resulted in large numbers of display commands being issued to the window system, ultimately creating a raster image of the quadtree. Experimentation showed that significant performance improvements could be gained by using adaptations of QUILT code to convert the quadtree to a raster directly and then pass the raster to the window system. Additions were made to the **qdisplay** process to accomplish this quadtree to raster conversion process and to pass the resultant raster to the application requesting it in a more efficient manner than is done for individual quadtree leaf nodes. In addition, modifications were made to the window system interface to perform raster replication to increase the scale of area of interest displays.

Several modifications were made during Phase II to the QUILT system itself at PGSC's request through a subcontract with the University of Maryland's Center for Automation Research, the developers of QUILT. These modifications were in three areas:

1) Support for the storage and retrieval of attribute data in PM quadtrees; 2) Support for the buffering of access to the segment array used to associate PM quadtree nodes with line segment identifiers; and 3) Making all error messages go to the standard error file, rather than some to the standard output.

During Phase III the only modifications made to the QUILT system itself were several minor corrections to some of the routines that dealt with initializing for reading PM (linear data) quadtrees that contained very large collections of segments, and several problems with C functions that would not pass a more stringently ANSI-C compliant 'C' compiler during the initial efforts aimed at porting QUILT to a VAX/VMS environment.

Several modifications were made to the **qdisplay** process which was derived from a variety of QUILT applications to correct or enhance execution speed when dealing with PM and P (point data) quadtrees. In addition several additions were made to that process to support the display of some 'overlays' as gray scale overlays over color base maps.

3.3.2 GIS Primitives used by Inference System

In addition to the primitives developed under Phase II, such as the determination of whether an area's terrain tends to channel movement as depicted in Figures 3-4 and 3-5, a variety of modifications were made to the GIS primitives used in Phase III rule base evaluation. Among these modifications were changes to the inference system primitive manager to better support the handling of missing data, the creation of new primitives to support Phase III rulebase developments, and the creation of new support GIS primitives used in the process of combining overlays to determine unique combinations of attribute values.

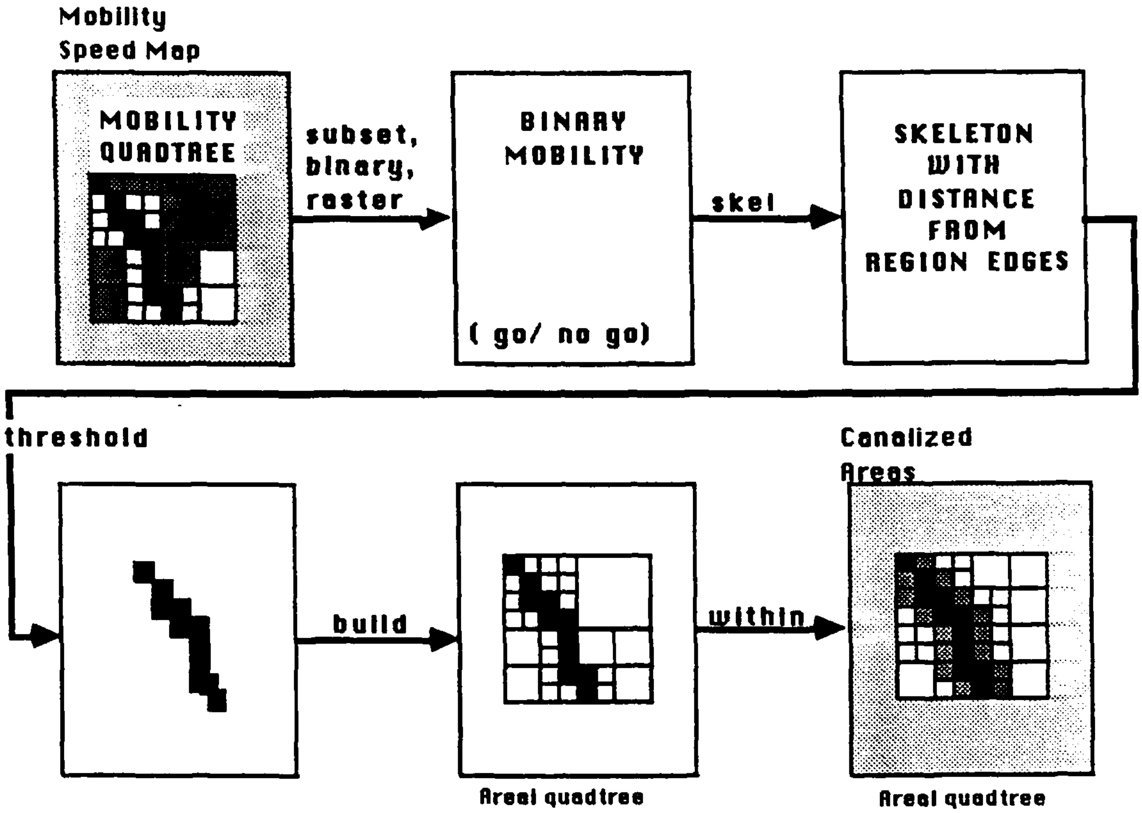
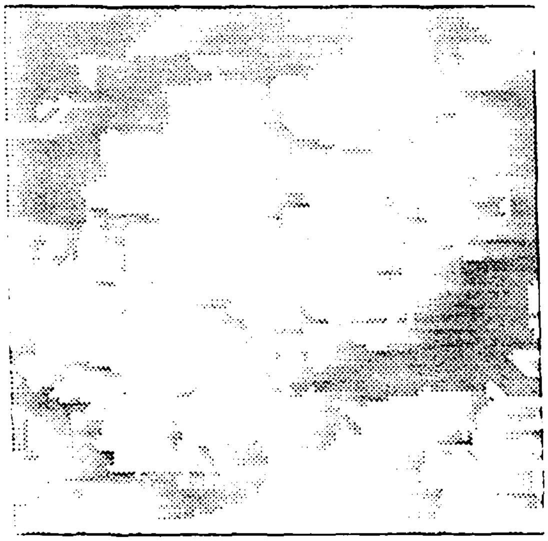
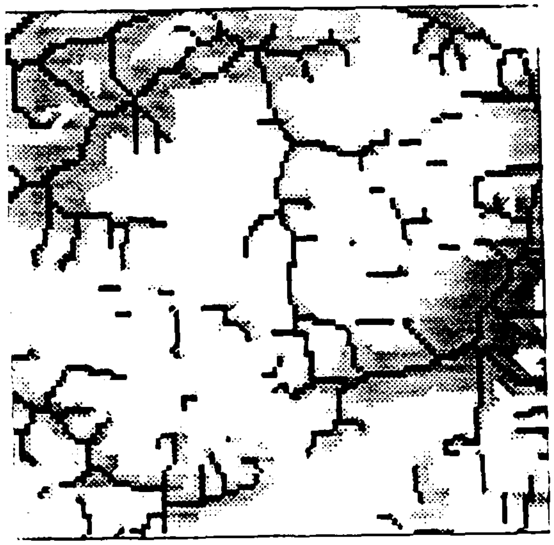


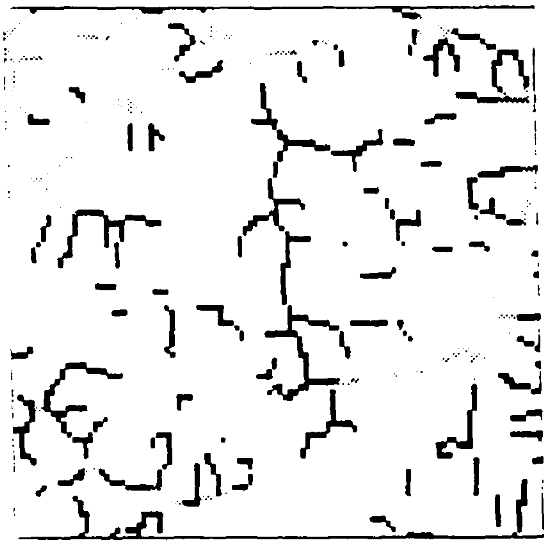
Figure 3-4. Conversion of Mobility Quadtree into Channelized Areas.



Traversable Areas



Skeleton of Traversable Areas



Segments Thinned in Threshold Iterations

Channelized Areas From Skeleton Segments

Figure 3-5. Determining Channeled Movement Areas from Areas of Mobility

The modifications to the primitive manager to support better handling of unavailable data were made so that the Phase II rulebase could incorporate all the aspects of minefield doctrine that knowledge engineering resulted in. With these modifications, as new data becomes available, only the primitives associated with that new data need to be developed, no inference system changes are required. Likewise, if the analyst wants to see what impact a particular terrain factor has on rule base evaluation, the system can simply be told that data is not available without making any rule base or software modifications.

Several new GIS primitives were created to support Phase III rule base evaluation. These included primitives to provide information about the minimum distance ranges to enemy locations (**dist_to_eloc**), and whether areas are visible or not (**visible**). In addition, a new version of the primitive that drives the minefield site prediction manuscript creation process was developed in support of Method II processing. This procedure, **qscan_dmpupd**, identifies areas with unique combinations of attributes, passes the identifier to the **Create Manuscript** application for evaluation by the inference system, and updates that area and every other area with the same combination of attributes with the inference system evaluation.

Finally, a number of new GIS primitives were created to support the creation of the manuscript template: the quadtree with identifiers for each combination of attributes derived from the area of interest overlays. The primitives **addall**, **addall_nonzero**, **changeall**, **compall**, **maxall**, and **orall**, which are actually simple subroutines in a larger controlling procedure body, implement simple quadtree operations required by the manuscript template creation process. Similarly, the GIS primitives **eloc_dist**, **elev_range**, and **fslp** create quadtrees defining the minimum distance range to enemy locations, elevation range classes from elevation values, and areas visible from enemy locations respectively.

3.4 Window System Interface

One of the goals of Phase II MSPES development was to ease the transition of the user interface portion of the MSPES to the Phase III target system, a VAXStation II/GPX running the VMS operating system. To that end, it was decided that the user interface used by MSPES applications would use a non-proprietary, portable window system graphics package: the X Window System. Although this transition to the target system did not occur, the MSPES window interface development continued under X Windows. A detailed discussion of the X Window system is provided in Section 3.4.1 of the Phase II Final Report [ETL-0534, May1989].

3.4.1 Application Control Panels

Each of the MSPES applications (**View Map, Create Manuscript, Input Map, Edit Rule base**, and **MSPES Help**) has a control panel. These control panels consist of command buttons and ancillary label information such as the name of the current Area of Interest, the current manuscript, etc. These application panels remain essentially the same as those developed under Phase II.

The MSPES control panels consist of a vertical array of buttons and labels. This arrangement has several benefits. First, the vertical arrangement is similar to the ALBE testbed user interface. It is an important aspect of user interface design, particularly of applications which use direct manipulation interfaces, that the user interface match the user's conceptual model. The MSPES uses a portable window system to create a familiar looking environment in which to perform interactions with geographic information. The ALBE testbed equivalent to the MSPES control panels are the command menus which appear on the alpha-numeric terminal and the control, message, and legend areas that appear along the right margin of the ALBE graphic terminals. Secondly, the arrangement of components within application windows is automatically maintained by components of X Toolkit widget sets; no MSPES code had to be developed to create this arrangement. The form widget permits child widgets, the buttons, labels, and graphic canvases used by the MSPES, to specify relative positioning hints to the parent form. These hints allow the child widgets to maintain their relative positions after resize events caused by the user modifying the application window arrangement. Finally, the default position for the MSPES control panels is along the right hand side of the graphics display. By positioning the control panel along the sides of the graphic terminal a larger, squarer area is left free for the graphics display.

Command buttons on application control panels sometimes appear 'grayed out' and cannot be selected by the user. This is controlled by the need to satisfy prior conditions before the command can be applied. For example, the DISPLAY button appears grayed out on the **View Map** application control panel until the user has selected an overlay or minefield site prediction manuscript using the LIST MAPS button. In this way the user is led through the process of using the application without having to remember a particular command sequence.

3.4.2 Graphic Viewport

The graphic viewport is where maps and manuscripts are displayed for MSPES applications that use them. The MSPES user interface displays the graphic viewport to the left of the control panel in an area that, by default, uses most of the screen real estate. Changes to the graphic viewport made under Phase III included support for the display of two overlays at once, scrollbars to permit the display of maps larger than the dimension sof the application window, and additional use of the X resource database to enhance customization and adaptation of the user interface without requiring recompilation of source code.

Graphic viewports are implemented using a simple widget created for MSPES applications. This widget is implemented by the routines in the Gwindow library. A Gwindow widget object provides methods for drawing text, lines, polygons, points, and displaying rasters, among other capabilities. Modifications were made to the Gwindow widget procedures to support the display of two overlays at once using X Window System colormap manipulations. A colormap is created with two sets of 32 colors each. In one set the 32 colors are used to display color base maps. The other set of 32 'colors' defines a gray scale which is used to display overlays on top of color base maps. The pixel values used for the second set of 32 'colors' parallel the pixel values used for the first set, except that they have one additional bit set. In effect, the second set of colors' pixel values defines a bit plane within the Gwindow widget display area. By enabling just that bit plane when 'overlays' are displayed, the color base map pixels are mapped into overlay gray shades. The implementation of these functions is hidden from applications and is readily modified to effect performance or functional improvements. The overlay capabilities are accessed by application requests that the Gwindow widget select the 'next' overlay.

Figure 3-6 depicts the MSPES **View Map** application user interface, illustrating a typical display using the components referred to above.

Figure 3-6.MSPES View Map application

3.5 User Interface

Under Phase III development a number of modifications were made to the user interface used by MSPES applications to facilitate customization to user requirements and modification to the graphic appearance of applications. These modifications include enhancements to the way in which the system 'knows' about overlays associated with an area of interest and the ability for the analyst to edit the Enemy Location overlay while another base map is being displayed to indicate enemy location by cursor point and click. Multiple enemy locations may be delimited.

During Phase II, the Explain Manuscript and Edit Map applications were incorporated as user-selected 'modes' of the View Map application. Using the 'grayed out' user feedback mechanism, these modes are only available when appropriate. For example, explain mode is available only when a manuscript is being displayed and not while edit mode is active. While viewing a manuscript, if the user wants to see an explanation from the inference system of the rule base logic that led to a minefield likelihood categorization, the user clicks on the EXPLAIN button. This causes the inference system to be primed and an explanation window appears. Clicking on a manuscript location causes the inference system to re-evaluate the specified position and permits the user to interact directly with the inference system via the explanation window. This situation is illustrated in Figure 3-7. This modification was kept under Phase III.

The X implementation of the MSPES control panels permits some of the appearance of the user interface to be customized readily by the user similar to the way in which user preferences for text editing tools may be specified. User interface customization is accomplished by specifying resource strings in an .Xdefaults file or by loading resource definitions into the window system server. Using these application resource specifications, the user can modify what font is used for command buttons and labels in the control panels, the label text itself, the width of borders, the color of borders, etc. The initial position and size of the MSPES user interface windows is likewise determined by resource definitions that the user is free to over-ride with private specifications. System default values are provided and are loaded as the applications are started. System default values may be overridden by the user loading replacement values prior to application start up.

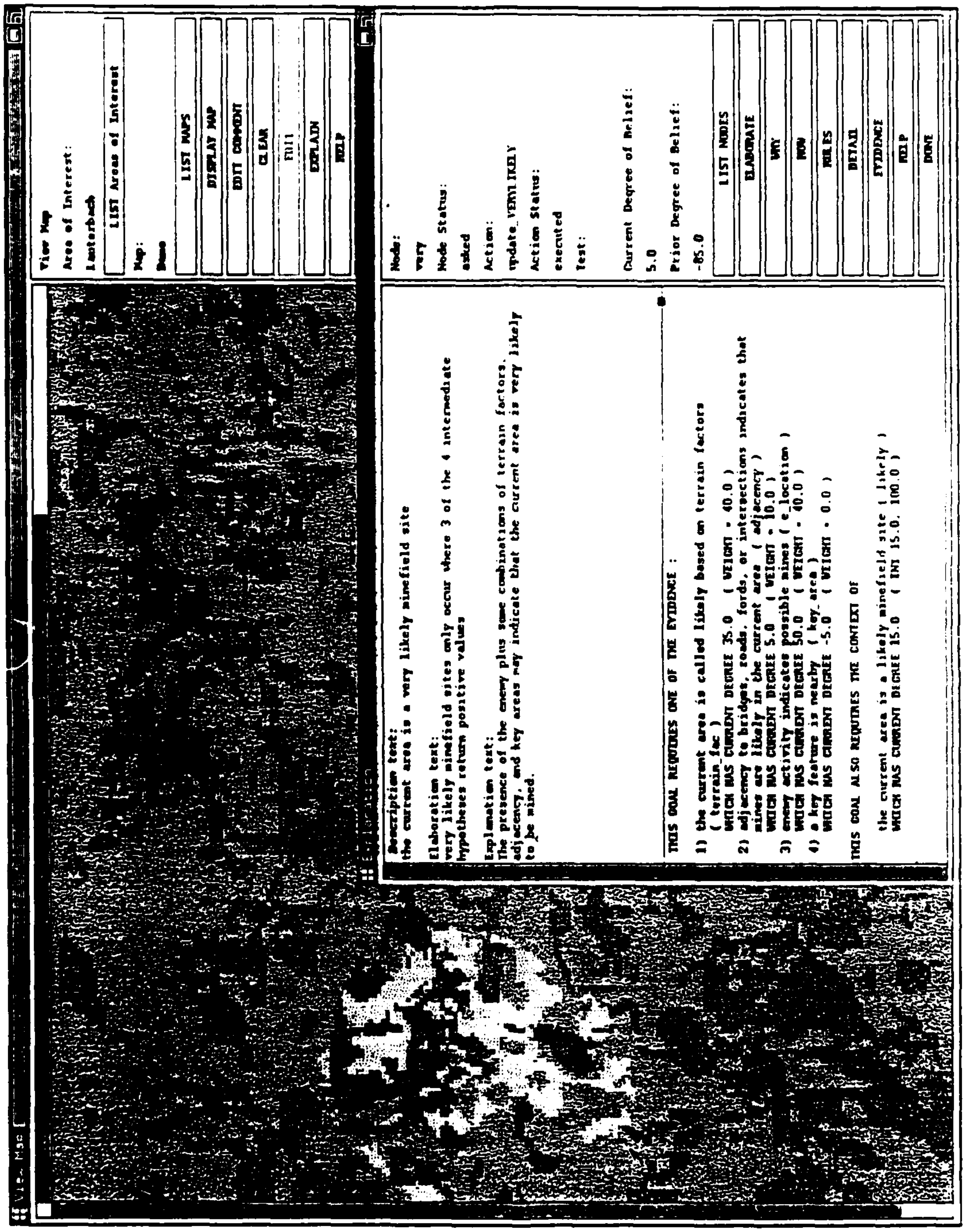


Figure 3-7. Explanation Mode of the View Map application.

The legend text associated with each type of map used is stored in a text file that is read and interpreted when the applications start a new map display. Under Phase II development, the association between overlays and the file describing the overlay's legend was hardwired into the applications. This made adding new types of data to the system a matter of recompiling source code. Under Phase III, the information about what overlays are associated with an area of interest, how the user identifies those overlays, how those overlays are to be displayed, how those overlays are created, and what GIS primitives are associated with those overlays for use during rule base evaluation is all specified in a text file that is read and interpreted when the user initiates the selection of an overlay. This enhancement makes the act of providing the system with knowledge about what overlays are associated with an area of interest and how they are to be utilized a matter of editing the area of interest **overlays** file.

Figures 3-8 through 3-10 illustrate the user interface and the enemy location facility using the elevation data overlay as a background display. Figure 3-8 shows five enemy installations, displayed as an overlay, clustered on two higher elevation areas on the left center of the an elevation range map, which is displayed as a color base map (here rendered in black and white). Figure 3-9 depicts the minefield belts of a deliberate defense established by the enemy. These belts or areas around the enemy location indicate varying weights contributed to the degrees of likelihood of a minefield site. Figure 3-10 delimits those areas which are visible to the enemy from enemy locations, shown as an overlay, and the surrounding topography shown as a color base map.

Figure 3-8. Enemy Installations Using A Cursor on An Elevation Map

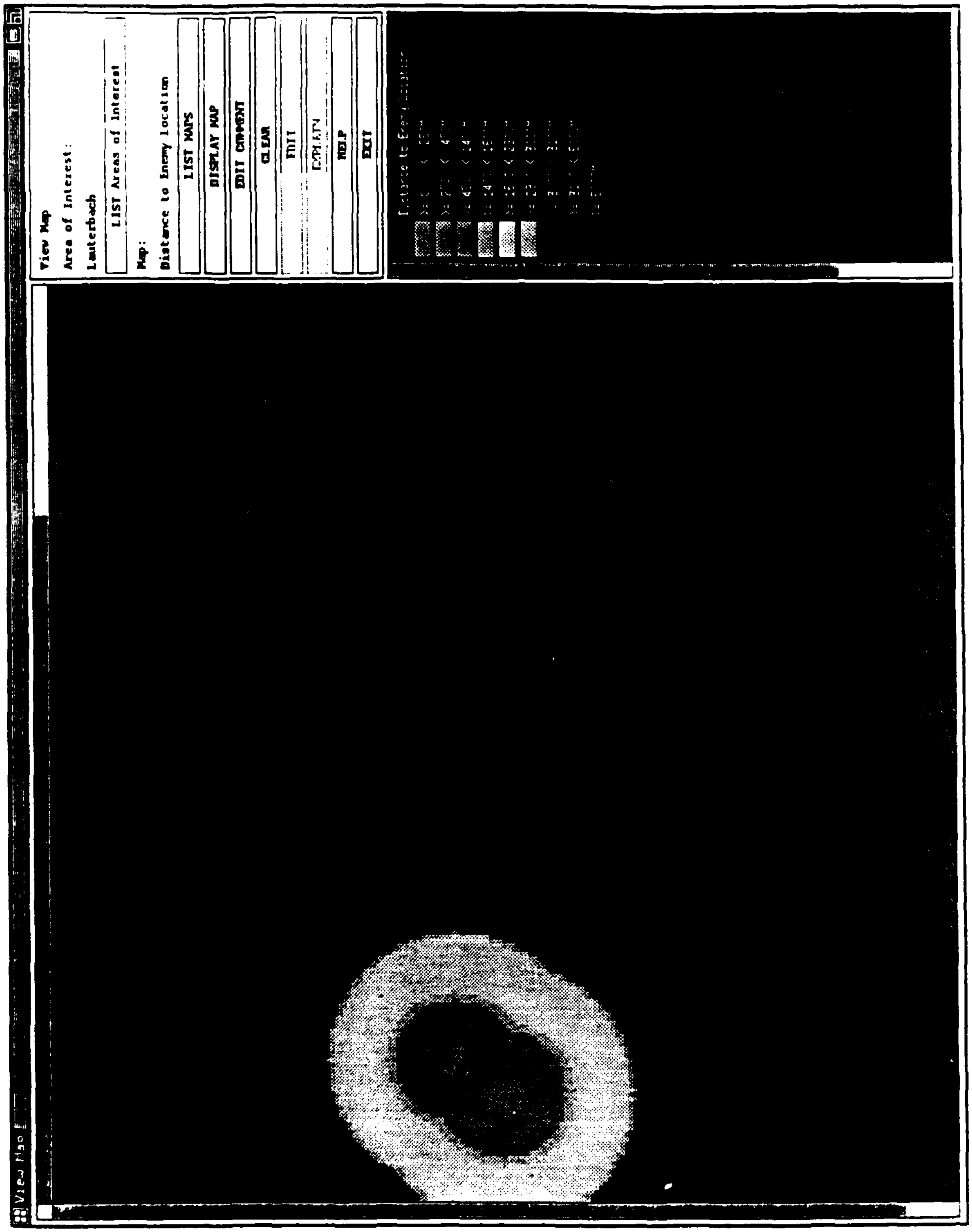


Figure 3-9. Areas of Deliberate Defense Around Indicated Enemy Location

Figure 3-10. Areas Visible to the Enemy from their Vantage Point

4. Evaluation and Recommendations

The following discussion focuses on the evaluation of the Phase III developments and the recommendations for future work involving the MSPES.

- The Phase III rule base could be extended and enhanced to more fully model the minefield site prediction process if more data were available in digital form. Data formats and availability were the greatest problems encountered during MSPES system development. A large amount of effort was expended on translating different data formats and circumventing data that was not available. An advantage of this is that the rule base design was constructed to accommodate data availability so that the system could perform even if data were not accessible.

- Given a different domain or even the current minefield site prediction problem, the GIS functionality of the MSPES could be extended. This includes both how the system uses the GIS functions and what GIS functions are available for use. Establishing a 'GIS toolbox' would greatly expand the utility and application of the MSPES. For example, implementing an interface between the core MSPES and a number of GIS such as GRASS, yet retaining the quadtree capability, would greatly enhance the current system.

- Porting the MSPES or interfacing the MSPES to the ALBE environment would provide a valuable Tactical Decision Aid (TDA) tool. The original scope of this effort called for the porting of this system to the ALBE system. The MSPES represents technology mature enough to move into the operations and development environment [PGSC, 1989].

- Exploring application of this system to other problem domains, including the use of cooperating expert systems, could provide useful information for future development efforts in support of the modern battlefield

- The MSPES should be reviewed and evaluated by both terrain analysts and combat engineers to assess the utility of combining inferencing systems and geographic information systems to .automate some of their functions.

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Appendix B - Terms and Abbreviations

CCM	Cross Country Movement
CVL	Computer Vision Laboratory. Refers to a raster data format used as the input format for QUILT areal quadtrees.
DEC	Digital Equipment Corporation
ERS	Embedded Rule-Based System
ETL	U.S. Army Engineer Topographic Laboratories
GIS	Geographic Information System
GPX	A trademark of DEC, a Graphics Accelerator chip set.
i/o	input/output
MIT	Massachusetts Institute of Technology
MSPES	Minefield Site Prediction Expert System
PGSC	PAR Government Systems Corporation
PM	Polygonal Map, a type of quadtree used to store linear data.
QUILT	A GIS developed by the University of Maryland Center for Automation Research.
SunOS	A trademark of Sun Microsystems Inc., the operating system used for the prototype and Phases II & III MSPES.
toolkit	A set of functions to simplify the development of application user interfaces.
UNIX	A trademark of AT&T Bell Laboratories, a multi-processing computer operating system
VAX	A trademark of DEC, standing for Virtual Address eXtension, describes a family of 32 bit super-minicomputer
VMS	A trademark of DEC, standing for Virtual Memory System, a high performance operating system that runs on the VAX family of computers.
widget	A user interface component in X11 with associated input and output semantics that implements a particular direct manipulation user interface style.
X11	A trademark of MIT, the X Window System

Appendix C - Phase III Rule Base

The following lists detail the rule base developed under Phase III.

Goals

Unevaluated
Possible
Likely
Very

Intermediate Hypothesis

terrain_fac
adjacency
e_location
key_area
ccm_possible
fast_ccm
ccm

Evidence Nodes

ccm: a choice node with a primitive, this eliminates having to have each node for a set of mutually exclusive function results call the same primitive function. The primitive ccm_class is called once with the resulting value compared to the seven specified answers. The seven ccm categories with a brief description are:

1) go: the region can support speeds greater than 30.0 km/hr,

2) restricted: the region allows speeds between 15.0 and 30.0 km/hr,

3) slow: the region permits speeds between 5.0 and 15.0 km/hr,

4) very_slow: the region permits speeds between 1.5 and 5.0 km/hr,

5) no_go: the region permits speeds less than 1.5 km/hr,

6) no_go_water: the region contains open water that cannot be crossed,

7) built_up: built-up areas restrict movement of battle tanks.

deliberate: a choice node with a primitive, this eliminates having to have each node for a set of mutually exclusive function results call the same primitive function. The primitive distance_to_e_loc is called once with the resulting value compared to the eight specified answers. The eight possible responses with a brief description are:

>=3100: the region is located beyond the range for the first minefield

>=2900_<3100: the region is located within the first minefield belt

>=1600_<2900: the region is located between specified minefield belts

>=1400_<1600: the region is within the second obstacle/minefield belt

>=450_<1400: the region is located between specified minefield belts

>=250_<450: the region is within the third minefield belt

>=0_<250: the region is located between specified minefield belts

<0: the region is located an unknown distance from minefield belts

e_loc_distance: a choice node with a primitive, this eliminates having to have each node for a set of mutually exclusive function results call the same primitive function. The primitive distance_to_e_loc is called once with the resulting value compared to the four specified answers. The four possible responses with a brief description are:

>5000: region is beyond range for enemy mines or visibility

>3000-5000: region is visible to enemy but located outside mine belts

0-3000: region is within range of enemy minefields

unknown: region is located an unknown distance from enemy position (enemy positions not specified)

canal_evid: Skeletonization and mobility data indicates the current area has characteristics of a canalized area. Canalized areas have a higher likelihood of being mined.

road_adj: Transportation data indicates a road is adjacent to current area. Mine documentation indicates areas adjacent to roads are likely to be mined.

inter_adj: Transportation data indicates an intersection of roads is adjacent to the current area. Mine documentation indicates areas adjacent to road intersections are more likely to be mined.

bridge_adj: Transportation data indicates a bridge is adjacent to the current area. Mine documentation indicates areas adjacent to bridges are more likely to be mined.

ford_adj: Transportation data indicates a known fording site is adjacent to current area. Mine documentation indicates areas adjacent to known fords are more likely to be mined.

near_e_loc: If current area is within 5000 meters of the enemy there is a greater likelihood of being visible to the enemy and within range of enemy artillery.

obstruction: Since mines are designed to slow down and modify patterns of mobility, the presence of other means to accomplish this, such as obstacles, is a positive indicator.

visible: The current area has a greater chance of being mined if it is within sight of the enemy and within range of enemy artillery.

range: The current area has a greater chance of being mined if it is within 3000 meters of enemy position. Based on a deliberate defensive posture the enemy will place mines in three bands starting at 3000 meters out from their current position. The second and first bands are laid at 1500 meters and 300-400 meters, respectively.

strongpoint: Areas that are suspected of possessing strongpoints will try to canalize the movement of tanks. Strongpoints are designed to be a cork in a bottleneck formed by terrain, obstacles, and units. It is essentially an antitank nest proving incapable of being bypassed.

ave_approach: If the current position is within an avenue of approach there is a high likelihood of mines.

installation: Minefields will be placed around key installation features. Minefield doctrine indicates mines are likely near and around key installation features such as airports, helicopter landing zones, and enemy military areas.

coastal: Tests to determine if current area is within a coastal area. Minefields are placed along flat coastal areas to inhibit beach landings of troops and artillery.